Extracting SUSY parameters from LHC measurements using Fittino

Philip Bechtle*, Klaus Desch†, Mathias Uhlenbrock† and Peter Wienemann†

*DESY, Notkestr. 85, 22607 Hamburg, Germany
†Dept. of Physics, University of Bonn, Nussallee 12, 53115 Bonn, Germany

Abstract. We show that presently available precision data are in good agreement with supersymmetry at a mass scale below 1 TeV. Using a SUSY point close to the best fit to present data, we give a projection of the capabilities of the LHC to constrain SUSY models and their parameters as function of the accumulated luminosity.

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INTRODUCTION

With the upcoming start of the Large Hadron Collider (LHC) we will be in the exciting situation to be able to probe physics at the TeV energy scale for the first time directly in a laboratory. There are numerous, very diverse reasons to expect new physics showing up at this energy scale. One of the most promising candidates for physics beyond the standard model is supersymmetry (SUSY). It is able to remedy various different shortcomings of the standard model by introducing a single additional symmetry between bosons and fermions.

If new physics can be established at the LHC, the most important objective will be to find out the underlying model and to determine its theory parameters. For such an inverse modelling task fitting packages like `Fittino` [1, 2] and `SFitter` [3] have been developed. For the results described in this work, `Fittino` has been employed. Sparticle properties for given SUSY parameters are calculated by the programs `SPheno` [4] and “`Mastercode`” [5, 6, 7]. Starting from a model and parameters which show good agreement with available measurements from LEP, SLC, Tevatron, *B* factories, WMAP and precision measurements at low energy, we present a projection of the expected inverse modelling performance as function of the accumulated LHC luminosity. A detailed description of this work can be found in [8].

FITS TO LOW-ENERGY DATA

Although so far there is no unambiguous experimental evidence for supersymmetric particles, there are a number of measurements which allow to put constraints on a supersymmetric theory. These include precision measurements and Higgs boson mass limits from the high energy colliders LEP, SLC and Tevatron, as well as information on

TABLE 1. Fitted mSUGRA parameters assuming $\mathrm{sign}(\mu) = +1$ together with SPS1a values.

Parameter	Best fit		Uncertainty	SPS1a
$\tan\beta$	13.2	$\pm$	7.2	10
$M_{1/2}$ (GeV)	331.5	$\pm$	86.6	250
M_0 (GeV)	76.2	$\pm$	$^{+79.2}_{-29.1}$	100
A_0 (GeV)	383.8	$\pm$	647	-100

rare decays of K and B mesons, the anomalous magnetic moment of the muon and the cold dark matter relic density as derived from cosmological measurements. A complete list of used measurements can be found in [8].

Various SUSY models are fitted to these measurements and constaints on the respective model parameters are derived. The tested models comprise mSUGRA with $\mathrm{sign}(\mu) = +1$, mSUGRA with $\mathrm{sign}(\mu) = -1$, GMSB with $\mathrm{sign}(\mu) = +1$ and $N_5 = 1,2,3,4$ and GMSB with $\mathrm{sign}(\mu) = -1$ and $N_5 = 1$. Since the lightest SUSY particle (LSP) in GMSB models is a very light gravitino making up hot instead of cold dark matter, the cold dark matter relic density measurement is excluded from the list of observables for GMSB fits. It turns out that mSUGRA with $\mathrm{sign}(\mu) = +1$ is in good agreement with the data. The corresponding best fit parameters are listed in Table 1. The sparticle masses corresponding to these parameters are all predicted to be below 1 TeV and should thus be discoverable at the LHC rather early.

It is striking that the fitted parameter point is in rather good agreement with the well studied SPS1a benchmark scenario [9]. For this benchmark point there is a wealth of detailed experimental Monte Carlo studies available. Apart from a significantly larger cold dark matter relic density, the phenomenology of SPS1a is very similar to the best fit point. We therefore use the expected measurements for SPS1a from the available experimental studies in order to try a projection of the low-energy fit results to the LHC era.

EXPECTED CONSTRAINTS FROM LHC DATA

The projections are performed for three different integrated LHC luminosities: 1 fb^{-1}, 10 fb^{-1} and 300 fb^{-1}. All results assume a centre-of-mass energy of 14 TeV. Wherever possible directly measurable observables are used as input to the fit. Many of them are endpoints of mass spectra. Most often the decay chain $\tilde{q}_L \to \tilde{\chi}^0_2 q \to \tilde{\ell}^{\pm}_R \ell^{\mp} q \to \tilde{\chi}^0_1 \ell^+ \ell^- q$ is exploited. Also mass peaks and two ratios of branching fractions are used. A full list of used input observables can again be obtained from [8].

mSUGRA model fits

The expected parameter uncertainties for an mSUGRA fit with fixed $\mathrm{sign}(\mu)$ is shown in Table 2. The scalar mass parameter M_0 and the gaugino mass parameter $M_{1/2}$ can already be constrained to the level of a few percent with an integrated luminosity of

TABLE 2. Expected uncertainties on mSUGRA parameters for integrated LHC luminosities of 1 fb^{-1}, 10 fb^{-1} and 300 fb^{-1}.

		Uncertainties		
Parameter	SPS1a	1 fb^{-1}	10 fb^{-1}	300 fb^{-1}
sign(μ)	$+1$			
$\tan\beta$	10	3.7	0.84	0.35
$M_{1/2}$ (GeV)	250	6.7	1.2	0.30
M_0 (GeV)	100	4.2	2.1	0.39
A_0 (GeV)	-100	742.1	52.9	11.1

1 fb^{-1}. More challenging are $\tan\beta$ and A_0. The uncertainties go down with increasing luminosity. At 300 fb^{-1}, M_0 and $M_{1/2}$ finally reach the (few) permille level and for $\tan\beta$ (A_0) a relative precision of 4 % (11 %) is achieved.

To determine sign(μ), two fits are performed to each (of many) toy datasets obtained by smearing observable values around the values for the best fit point. One fit assumes sign(μ) $= +1$ and the other one uses sign(μ) $= -1$. The χ^2 correlations of the fits with sign(μ) $= +1$ and sign(μ) $= -1$ allow to choose the most probable sign(μ) and to determine the probability for this choice to be right or wrong. Already at 1 fb^{-1} there is a good chance to determine sign(μ) correctly. The probability for an incorrect decision is less than 5 %. For 10 fb^{-1} or more luminosity, sign(μ) can be determined with negligible error probability.

MSSM18 model fits

Performing an mSUGRA fit implies strong constraints on the sparticle masses and couplings due to the assumed SUSY breaking mechanism. It is also interesting to fit more general models to the data without making assumptions on the high-scale behaviour and derive properties of SUSY breaking from weak-scale parameters using a bottom-up approach. The Lagrangian of the most general minimal supersymmetric standard model (MSSM) introduces more than 100 SUSY parameters, but excluding flavour-non-diagonal and CP-violating terms and assuming (effective) universality of the first two generations reduces the number of parameters to 18. We refer to this model as MSSM18.

The outcome of an MSSM18 fit to combined low-energy and LHC data with 300 fb^{-1} of luminosity is summarised in Table 3. Some parameters are determined with reasonable precision but there are also some which are only weakly constrained. Particularly difficult to measure are those parameters which characterise third generation sfermion properties and the Higgs sector parameters. The reason for the weak constraints in these sectors is that they are only partially accessible at the LHC. For the considered parameter point, the heavy Higgs bosons, for instance, are not expected to be discovered at the LHC. The situation can be improved significantly by including measurements at a future e^+e^- linear collider. In that case the precision on many parameters is one or two orders of magnitude better.

TABLE 3. Expected uncertainties on MSSM18 parameters from a combination of low-energy and expected LHC measurements for an integrated luminosity of 300 fb^{-1}.

Parameter	Nominal value		Uncertainty (LE+LHC300)
$M_{\tilde{\ell}_L}$ (GeV)	194.31	$\pm$	6.4
$M_{\tilde{\ell}_R}$ (GeV)	135.76	$\pm$	10.5
$M_{\tilde{\tau}_L}$ (GeV)	193.52	$\pm$	43.0
$M_{\tilde{\tau}_R}$ (GeV)	133.43	$\pm$	38.2
$M_{\tilde{q}_L}$ (GeV)	527.57	$\pm$	3.4
$M_{\tilde{q}_R}$ (GeV)	509.14	$\pm$	9.0
$M_{\tilde{b}_R}$ (GeV)	504.01	$\pm$	33.3
$M_{\tilde{t}_L}$ (GeV)	481.69	$\pm$	15.5
$M_{\tilde{t}_R}$ (GeV)	409.12	$\pm$	103.8
$\tan\beta$	10	$\pm$	3.3
μ (GeV)	355.05	$\pm$	6.2
X_τ (GeV)	-3799.88	$\pm$	3053.5
X_t (GeV)	-526.62	$\pm$	299.2
X_b (GeV)	-4314.33	$\pm$	5393.6
M_1 (GeV)	103.15	$\pm$	3.5
M_2 (GeV)	192.95	$\pm$	5.5
M_3 (GeV)	568.87	$\pm$	6.9
m_A (GeV)	359.63	$\pm$	$^{+1181}_{-99.3}$

CONCLUSIONS

Presently available precision data are in good agreement with SUSY masses below 1 TeV and thus an early discovery at the LHC is possible. For a SUSY point close to the best fit to present data, we show that even in rather general models like the MSSM18, the LHC (with ultimate luminosity) will allow for a determination of the SUSY parameters with reasonable precision except for third generation sfermion and Higgs sector parameters. In more constrained models like mSUGRA the achievable precision will be typically higher by one order of magnitude.

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